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13. ABSTRACT (Maximum 200 Words) Increased awareness and systematic screening for breast cancer has resulted in early detection of this disease. However, 20 – 30% of node negative breast carcinoma patients will develop recurrent tumors and given the highly metastatic nature of breast cancer, many of these patients progress to disseminated disease. Although developments in experimental therapies for the treatment of advanced breast cancer is promising, much of the existing treatment for advanced metastatic cancer is palliative. Among the numerous symptoms of advanced cancer , pain remains the most significant determinant of quality of life . Despite pain being the most feared symptom of advanced cancer, clinical management of cancer pain remains inadequate. Limitation in the clinical management of advanced cancer pain appears multifactorial ranging from the nature of pain itself to the irrational fear of prescribing large quantities of opiates among the treating physicians. The goal of this investigation is to develop a novel non-opioid approach to pain management. Our present focus is on antisense-oligonucleotide-mediated knock down of an intracellular signal transduction molecule protein kinase C-γ known to play a critical role in the development of pathological pain. If successful, a new therapeutic modality will have wide spread applications in the management of terminal cancer pain and other intractable pain syndromes.					
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4. Introduction

Increased awareness and systematic screening for breast cancer has resulted in early detection of this disease. However, 20 – 30% of node negative breast carcinoma patients will develop recurrent tumors [Weidner, 1995] and given the highly metastatic nature of breast cancer, many of these patients progress to disseminated disease [Lee, 1983]. Although developments in experimental therapies for the treatment of advanced breast cancer is promising, much of the existing treatment for advanced metastatic cancer is palliative. Among the numerous **symptoms of advanced cancer**, pain remains the most significant determinant of **quality of life** [Heim & Oci, 1993; Portenoy, 1990; Daut & Cleeland, 1982]. Despite pain being the most feared symptom of advanced cancer, clinical management of cancer pain remains inadequate. Limitation in the clinical management of advanced cancer pain appears multifactorial ranging from the nature of pain itself to the irrational fear of prescribing large quantities of opiates among the treating physicians [Fife et al, 1993; Zenz & Strumpf, 1993]. A novel non-opioid approach to pain management which requires minimal high-technology resources will have wide spread applications in the management of terminal cancer pain and other intractable pain syndromes.

In this proposal, we describe a **novel viral-vector mediated gene-therapeutic approach to pain management**. This notion is based on well documented observations that all vertebrate nervous system including humans posses an endogenous analgesic system. Of the numerous neurotransmitter systems implicated in such an endogenous analgesic system, one of the best described descending analgesic mechanism is the brain stem serotonergic input to the spinal cord. Stimulation of brain stem neurons result in release of serotonin, an amine neurotransmitter, at the spinal cord which modulates the transmission along the pain pathway. The original goal of this project was to examine if enhancement of this endogenous serotonergic analgesic system can provide analgesia. Our approach was to introduce a recombinant adenovirus designed to express one subtype (5HT3) of the serotonin receptor into the subarachnoid space as a means of overexpressing the 5HT3 receptor in spinal neurons. As documented on the last progress report, we concluded that intrathecal Ad(5HT3-sense) administration had little effect on nociceptive threshold in rats. A reexamination of adenoviral access to the spinal cord proper led us to conclude that a 100 nm adenovirus particle was too large to cross into the spinal cord proper even after subarchnoid administration. This led us to propose an alternative approach to gene therapy for pain managment through intrathecal injection of antisense oligonucleotide targeting protein kinase C- γ , an intracellular signal transduction molecule well documented to play a critical role in neuropathic pain.

5. Body

In this reporting period (Year II of the project), we focused our efforts on the development of an alternative strategy for gene-based therapy for neuropathic pain. Specifically, we targeted an intracellular pronociceptive signal transduction molecule, protein kinase C- γ , strongly implicated in mediating the pain cascade [Mao et al, 1995; Malmberg et al, 1997], and began investigating the use of antisense oligonucleotide [Agrawal & Temsamani, 1996; Akhtar & Agrawal, 1997] as a potential therapeutic drug. The antisense oligonucleotide approach was chosen because the PI believes that this strategy, in addition to its proven utility as a selective

drug in other systems, is a technology most likely to lead into a human clinical trial in the near future [Akhtar & Agrawal, 1997; Diasio & Zhang, 1997].

The following progress have been made on the revised Task II stated on the last progress report:

Task II:

- *perform further in vitro antisense oligonucleotide PKC- γ knock down experiments to verify the mechanism of protein knock down.*
- 1. Several candidate antisense oligonucleotides were identified based on sequence comparison of the classical PKCs (figure 1). *In vitro* antisense knock down experiment demonstrates differential efficacy in reducing the amount of PKC γ protein (figure 2). All 11 oligonucleotides tested to date (O1 – O11) demonstrate some degree of reduction in PKC- γ protein. O4, O6, and O9 demonstrating best knock down. The result for O6 is in agreement with our preliminary data presented on our last progress report. In contrast, O7 show only a modest efficacy.
- 2. We have encountered problems in demonstrating efficient antisense knock down of PKC- γ , in vivo. Various dosing regimen have been tried (up to 100 μ g / dose x q 12 hours) without consistent correlation between behavioral analgesia and biochemical evidence of spinal cord PKC- γ protein reduction. We have revised our behavioral pain assay from a partial sciatic nerve ligation to a formalin (inflammatory) model of pain. Since chronic pain associated with cancer often exhibits a strong inflammatory component, the formalin model may be more appropriate.

During the next funding period, the following aims will be accomplished:

- a. A time course experiment to develop an optimal protocol for in vivo knock down using Western blot assay of spinal cord homogenate.
- b. A time course study to examine the return of PKC- γ protein level after cessation of the antisense treatment. This information will help design an *in vivo* protocol to examine whether interruption of the pain cascade will provide a long-term relief from pain. Alternatively, pain could return immediately after cessation of the antisense treatment as the cells regenerate PKC- γ .
- c. *In vivo* studies examining anti-nociceptive effects of anti-PKC- γ antisense oligonucleotide will be continued with focus on the formalin model of inflammatory pain.

6. Key Research Accomplishments:

- Developed an alternative strategy based on antisense oligonucleotide knock down of protein kinase C- γ playing a critical role in the neuropathic cascade.
- Screened antisense oligonucleotides to identify a sequence leading to selective PKC- γ protein knock down.
- Demonstrated anti-nociceptive effect of intrathecal administration of antisense oligonucleotide targeting PKC- γ .

7. Reportable Outcomes:

Manuscripts / abstracts / presentations:

Wu C, Garry M, Zollo R, Yang J "Gene therapy for the management of pain Part I: Methods and strategies", *Anesthesiology*, (in revision).

Wu C, Garry M, Zollo R, Yang J "Gene therapy for the management of pain Part II: Molecular targets", *Anesthesiology*, (in revision).

Zollo R, Malik S, Yu J, Yang J "Antisense oligonucleotide-mediated selective knock down of protein kinase C γ ", (in preparation).

Yang J, Garry M, Zollo RA "Protein kinase C-gamma and neuropathic pain", Abstract FF-11, Era of Hope Meeting, 6/8-12,2000, Atlanta, GA.

8. Conclusions:

Inadequate management of cancer pain has been widely documented and may effect a reduction of quality of life in terminal patients [Heim & Oci, 1993; Portenoy, 1990; Daut & Cleeland, 1982]. Furthermore, neuropathic pain, which may be present with advanced cancer is generally resistant to opioid therapy [Payne, 1993; Arner & Myerson, 1988]. Development of a non-opiate, non-addictive, long-lasting therapy for cancer pain will revolutionize clinical cancer pain management and alleviate patient suffering. The goal of this proposal is to investigate the feasibility of a gene-therapeutic approach to pain management. Should this approach prove feasible, in future work, this concept can be extended to overexpression of other neurotransmitter receptors implicated in the antinociceptive action (e.g. GABA_A, adrenergic α_2 , etc.) or underexpression of receptors mediating the nociceptive actions (e.g. NMDA, tachykinin, etc.) through antisense knock down.

The original goal was to use the recombinant adenovirus as a vehicle for overexpressing antinociceptive serotonin type 3A receptors in the spinal cord as a means of providing pain relief. Our results over the first 12 months indicated that the recombinant adenovirus delivered by the subarachnoid route will not work. The physical barrier probably due to the marginal glial cells of the spinal cord prevents the adenovirus from transducing spinal cord neurons. Without efficient transduction of the spinal cord proper, the proposed approach will not work. Direct injection of the virus into the spinal cord is an alternative delivery method, but remains unsatisfactory because the approach is too invasive for easy translation to the human clinical arena.

We have taken an alternative strategy to accomplish the same goal of developing a treatment for neuropathic pain. During the present reporting period, we explored antisense oligonucleotide targeting spinal cord protein kinase C- γ as a therapeutic strategy for a non-opioid pain management. Progress thus far has identified several candidate antisense oligonucleotides that exhibit PKC- γ protein knock down. We will continue to this investigate antisense oligonucleotide as a novel alternative to opioids for treating neuropathic pain. Antisense oligonucleotide is now well accepted as a form of therapy in humans. It is our goal to thoroughly investigate the antisense oligonucleotide

targeting spinal cord PKC- γ in a preclinical model and move towards implementing a clinical trial in humans. Task for year 3 of funding will focus on in vivo assay of efficacy of PKC- γ antisense oligonucleotide. We hope to move a step closer to the goal of developing a novel and effective pain relief with reduced side-effects for combating the diverse types of pain associated with advanced cancer. In this respect, the antisense oligonucleotide approach may be more practical than the viral vector approach.

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Figure 1: Amino acid sequence alignment of classical rat PKC isoenzymes. The entire coding sequence for PKC- α (E04372), PKC- β 1 (M19007), and PKC- γ (E04371) were aligned using DNAsis (Hitachi Inc, CA). Genebank accession numbers are given in parenthesis. Regions of significant amino acid divergence were identified and thirteen oligonucleotides corresponding to the selected amino acid regions were defined as the candidate antisense oligonucleotides noted as O1 – O13 (noted in red). The PS oligonucleotide (in blue) was designed against a conserved region in the psuedosubstrate domain. Three of the well defined functional domains of the classical PKCs are identified by the green brackets. PKC- β II with 95% amino acid identity with β I was omitted from the figure for clarity.

	O1	O2		PS		
1	MADVYPANDS	TASQDVANRF	ARRGALROKM	WHEWVDHKFI	ARFFKQPTFC	psuedo-substrate domain
1	MADPAAGPPP	SEGEESTVRF	ARRGPIRQKM	WHEWVMHKFT	ARFFKQPTFC	
1	MAGLGPEGGD	SEGGPRPL-F	CRKGALROKV	WHEWVSHKFT	ARFFKQPTFC	
..	60	70	80	90	100	
51	SHCTDFIMGF	GKQGFQCCVC	CFVWHKRCHE	FVTFSCPGAD	KGPDITDDPRS	
51	SHCTDFIMGF	GKQGFQCCVC	CFVWHKRCHE	FVTFSCPGAD	KGPASDDPRS	
51	SHCTDFIMGF	GKQGLQCCVC	SEVWERRCHE	FVTFECPGAG	KGPQITDDPRN	
	110	120	130	140	150	
101	KHKFKIHTYG	SPTFCDHCGS	LLYGLIHQGM	KCDTCMMNVH	KOCVIMVPSL	
101	KHKFKIHTYS	SPTFCDHCGS	LLYGLIHQGM	KCDTCMMNVH	KRCVMNVPSL	
101	KHKERLESYS	SPTFCDHCGS	LLYGLVHQGM	KSCCEMMNVH	KRCVRSVPSL	
	160	170	180	190	200	
151	CGVDHTERRG	RIYLKAEV-F	DEKLHVTWRD	AKNLIPMDPM	GLSDPYVKLK	O3, O4
151	CGVDHTERRG	RIYIOMHI-D	REVLIWTVRD	AKNLVPMDDPM	GLSDPYVKLK	
151	CGVDHTERRG	RLQLEIRAPT	SDEIHTITWGE	AKNLIPMDPM	GLSDPYVKLK	
	210	220	230	240	250	
201	LIPDPKNESEK	QKTKTIRSTL	MPQWNESETE	KLEKPSDKDRR	LSVEIUDMDR	
201	LIPDPKNESEK	QKTKTIKCSL	MPQWNETRRE	QLEKPSDKDRR	LSVEIUDMDL	
201	LIPDPRLTLE	QKTKTVKATL	MPVQWNETRE	NLEKPGDVERR	LSVEIUDMDR	
	260	270	280	290	300	
251	TSRMDFMGSL	SFGVSEIMEM	PASGMYKLLM	QEEGEYVNVF	IPEGDEEGNV	O5
251	TSRMDFMGSL	SFGISELQRA	GVDGMFKLLS	QEEGEYVNVF	VPPEESEGNE	
251	TSRMDFMGAM	SFGVSELKKA	PVDGMYKLLM	QEEGEYVNVF	WADAD---MC	
	310	320	330	340	350	
301	ELRQKFE---	-----KAK	LGPAGNKVIS	PSED---RQK	P--SNMLDRV	O6 – O9
301	ELRQKFE---	-----RAK	IQGQTKAPEE	KTANTISKFD	N--NGMRDRM	
301	SLLRQKFEACN	YPLELYEVR	MGPSSSPIPE	PSPSPDSEK	CFFGASPGSL	
	360	370	380	390	400	
351	KLTDFNFMV	LKGSGFGKWM	LAEKRGTEEL	YATKILKNDV	VIQDDVVECT	ATP binding domain
351	KLTDFNFMV	LKGSGFGKWM	LSERKGTDEL	YATKILKNDV	VIQDDVVECT	
351	HISLDFNFMV	LKGSGFGKWM	LAERKGSDEL	YATKILKNDV	IVQDDVDECT	
	410	420	430	440	450	
401	MVEKRVLALL	DK-----PPF	LTQLHSCFOT	MDRLYFVMEY	VNGGDLMYHI	O10
401	MVEKRVLALP	GK-----PPF	LTQLHSCFOT	MDRLYFVMEY	VNGGDLMYHI	
401	LVEKRVLALG	GRGPGGRPHF	LTQLHSTFOT	PDRLYFVMEY	VTEGDLMYHI	
	460	470	480	490	500	
451	QQVGRFKEPQ	AVFYAAETSI	GLFFLHKRCI	IYRDLKLDNV	MLDSEGHIKI	phosphoryl-transfer domain
451	QQVGRFKEPH	AVFYAAETAI	GLFFLQSKCI	IYRDLKLDNV	MLDSEGHIKI	
451	QQLEKFKEPH	AAFYAAETAI	GLFFLHNQCI	IYRDLKLDNV	MLDAEGHIKI	
	510	520	530	540	550	
501	ADFGMCKEHN	MDGVITRTFC	GTPDYIAPET	IAYQPYGKSV	DMMAVGVLLY	O11
501	ADFGMCKEMI	WDGVITRTFC	GTPDYIAPET	IAYQPYGKSV	DMMAFGVLLY	
501	TDFGMCKENV	FPESITRTFC	GTPDYIAPET	IAYQPYGKSV	DMMSFGVLLY	
	560	570	580	590	600	
551	ENLAGQPPFD	GEDEELFQS	IMEHNVSYPK	SLSKEAWSIC	KGLMTHKPGK	
551	ENLAGQAPFE	GEDEELFQS	IMEHNVAYPK	SMSKEAWAIC	KGLMTHKPGK	
551	ENLAGQPPFD	GEDEELFQA	IMEQTWYYPK	SLSREAWAIC	KGFLTKHPGK	
	610	620	630	640	650	
601	RLCCGPEGER	DVREHAFFRR	IDWEKLENRE	IQPPFKPKVC	GK-GAENFDR	
601	RLCCGPEGER	DIKEHAFFRY	IDWEKLENKE	IQPPFKPKAR	DKRDTSMFDR	
601	RLSECPDEEP	TIRAHCFRW	IDWERLERLE	IAPPERPRPC	G-ESGENFDR	
	660	670	680	690	700	
651	FFTRGQPVLT	PPDQLVIANI	DQSDREGFSY	VNPQFVHIL	QSA-----	O12
651	FFTRQPVLT	PTDKLFIIML	DQNEFAGFSY	TMPEFW----	-IN-----	
651	FFTRAAALTI	PPDRLLWLST	DQADFGQFTY	VNEDFWHDA	RSPTSPVPVP	
	710	720	730	740	750	
701	-W*	O13
701	-W*	
701	VM*	

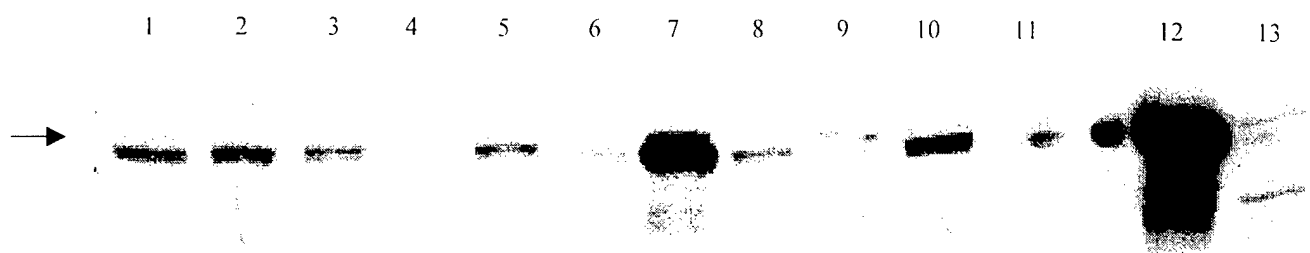


Figure 2: *Differential reduction of PKC- γ by selected antisense oligonucleotides.* Western blot of PKC- γ protein in antisense oligonucleotide-treated cells. Lanes 1 – 11 corresponds to antisense oligonucleotides O1 – O11 shown in figure 1. Lane 12 is a positive control without oligonucleotide treatment and lane 13 is a negative control. Individual 35 mm tissue culture dishes 70% confluent with HEK293 cells were co-transfected with PKC γ -pCIneo (0.2 μ g / dish) and 1.0 μ g / dish oligonucleotide using Lipofectamine Plus (Gibco). Twenty four hours after termination of transfection, cells were harvested and equal amount of protein loaded and separated by SDS gel electrophoresis.